RESULTS OF A CONTINUOUS TRANSATLANTIC TWO-WAY TIME TRANSFER TEST USING COMMERCIAL SATELLITE MODEMS

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Abstract

This paper is the second in a two-part series that introduces the concepts of two-way time transfer using commercial satellite modems. The first paper [1] presented the concept of time-based communication and detailed multiple implementations using satellite channels. This paper presents the results of a transatlantic proof-of-concept demonstration of the technology. A short review of time-based communications is presented, followed by a detailed description of the test. Results are presented and data examined for consistency over time and temperature.

1.0 TIME-BASED COMMUNICATION

Time-based communication is a technology in which an active data communications channel is utilized as a vehicle for two-way time transfer. The impetus for the development of this technology is the existence of users with stringent timing requirements and existing or planned communications infrastructures. Time-based communication provides very precise time transfer capability in the background of a data transfer channel. This allows two ends of a communications link to be precisely synchronized without fielding an independent timing system.

Time-based communication is a generic technology with a few basic requirements [1]. The data channel must be duplex using a medium that has uniform delay characteristics over the time of the measurement. Implementation of these concepts has been accomplished over fiber [2] and satellite channels [1]. In this paper, an over-the-air (OTA) system is evaluated using commercial satellite modems between Europe and the United States.

The different tasks performed by the modem in the OTA system are seen in Figure 1. The top (darker shade) section contains the typical communications tasks. These tasks, from the administration of the link to the actual transfer of data, are performed in order to transfer data from one end of the link to the other. The bottom section (lighter shade) shows the timing tasks that are performed in the background of the data link. These tasks, detailed in reference 1, include injecting a pattern to measure, measuring the pattern at each end of the link,and exchanging measurement data.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE
NOV 2000

2. REPORT TYPE

3. DATES COVERED
00-00-2000 to 00-00-2000

4. TITLE AND SUBTITLE
Results of a Continuous Transatlantic Two-Way Time Transfer Test Using Commercial Satellite Modems

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Zeta Associates,10302 Eaton Place Suite 500 ,Fairfax,VA,22030

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
See also ADM001509. 32nd Annual Precise Time and Time Interval (PTTI) Meeting, 28-30 Nov 2000, Reston, VA

14. ABSTRACT
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15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**9**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

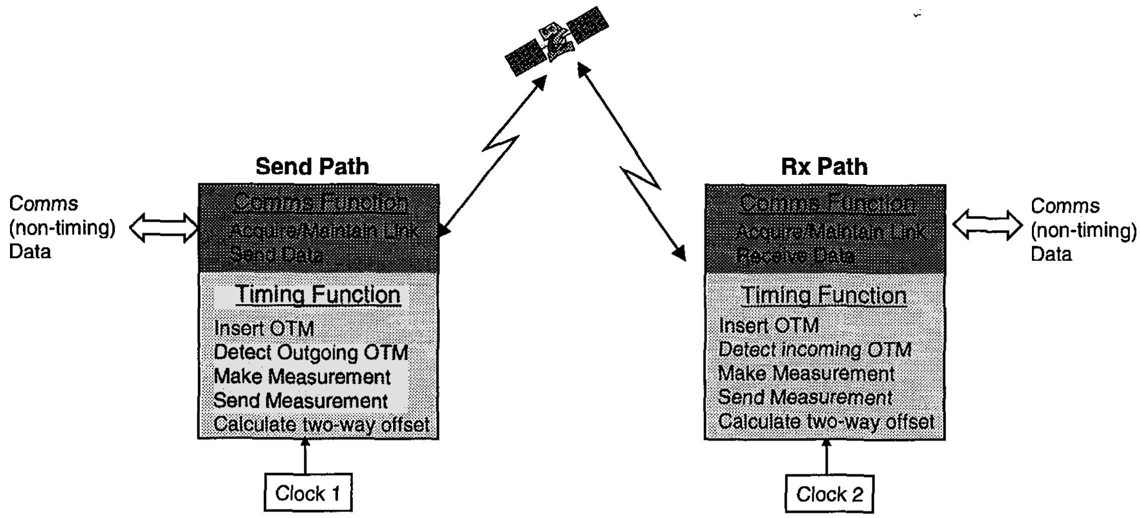

Figure 1: OTA Modem Responsibilities

2.0 HARDWARE CONFIGURATION

Figure 2 depicts the hardware implementation used for the demonstration. The OTA system was fielded between a site in Europe and a site in the United States. The two sites use identical GPS-based systems (darkly shaded elements in Figure 2) for timing recovery where passive GPS data are processed to steer a local cesium. Cross-site time synchrony is achieved by virtue of the fact that each site steers to a common reference, UTC(GPS). The OTA system (lightly shaded elements in Figure 2) was connected to the on-time point at each site. The OTA system produced a measurement of the cross-site time offset.

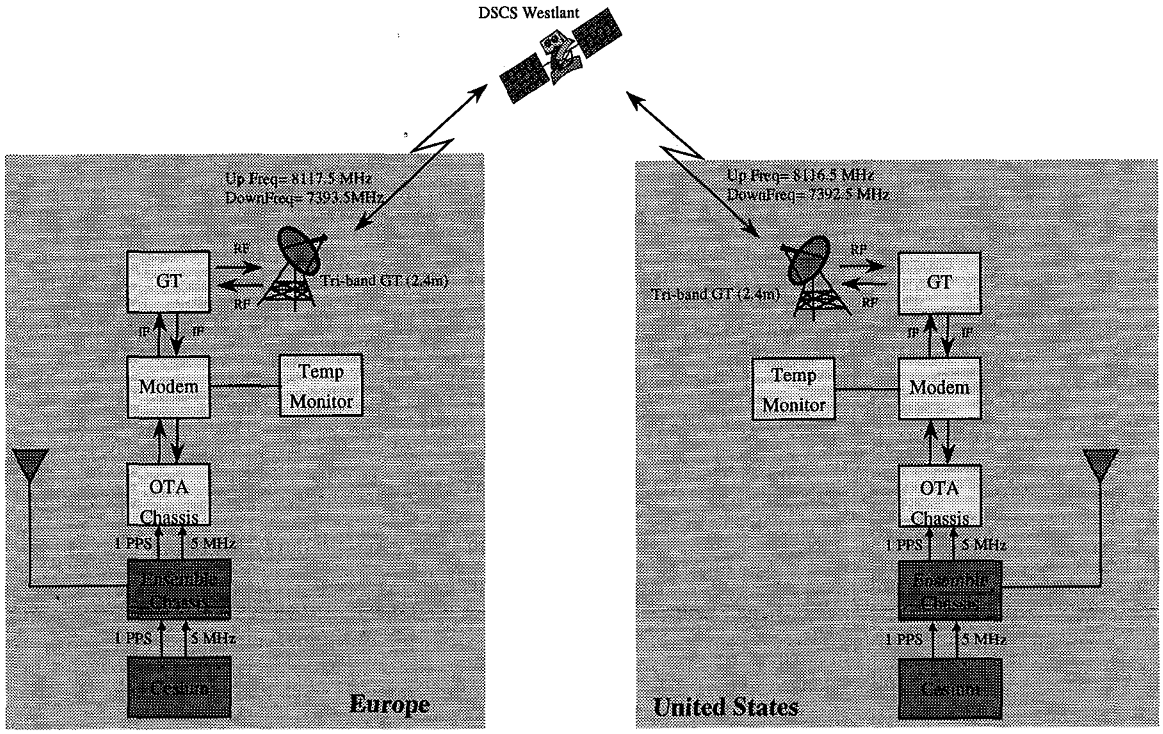

Figure 2: Demonstration Hardware Configuration

The OTA hardware consists of three significant pieces: the ground terminal, the modem, and the measurement hardware. An additional chassis for temperature measurements was also included (temperature compensation is discussed in Section 4.2). The ground terminal used for this test was a mobile 2.4 meter, tri-band dish. The dish (seen deployed in Figure 3) is owned and operated by the US Air Force Mobile Communications Unit (MOCOMM). The modem is a commercially available satellite communications modem manufactured by Radyne/Comstream. The measurement equipment consisted of a Timing Solutions chassis with precision timers run from a pentium controller.

The satellite channel for the test was a 256 kbs duplex link using the DSCS Westlant satellite. X-Band frequencies were used for uplinks and downlinks to/from the sites. The system was calibrated using identical frequencies and transponders after the test. This was possible due to the use of mobile terminals that could be fielded as two ends of a link and then co-located after the test for calibration.

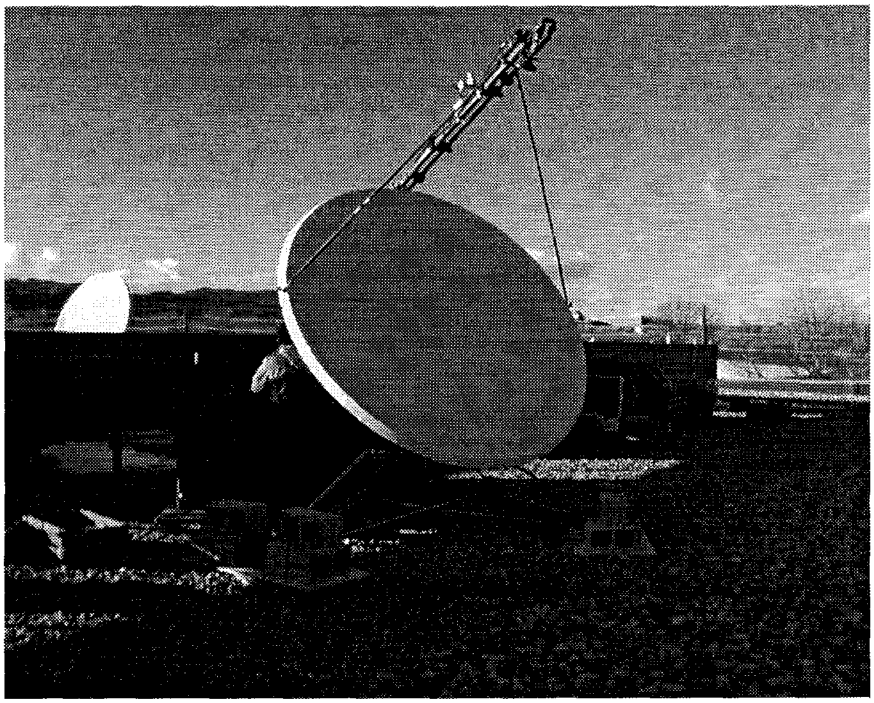

Figure 3: MOCOMM Tri-Band Ground Terminal

3.0 TEST RESULTS

Data were collected over a 9-day period for this test. The resulting measurement is seen in Figure 4. The blue curve is the post-processed OTA data. The raw 1-second data were processed using a running 900-second average to produce the continuous plot in Figure 4. The data have been corrected for Sagnac effect (239 ns), temperature differences, and absolute delay differences in the modems. The standard deviation of the data set is below 1 ns and the quality of the data is sufficient to see the motion of the clocks at the two ends of the link (each system is actively steering).

The data in Figure 4 provide a continuous record of the cross-site timing performance over the demonstration period. The first 5 days show steady-state operation of the systems. On mjd 51853, the cesium at one end reached end-of-life and its performance began to degrade. This is evident in the data set by the increased noise level and 25ns movement in the plot. The cesium was removed and replaced on mjd 51855. The plot in Figure 4 shows the system recovery as the GPS filter learns the frequency of the new clock after the cesium was replaced.

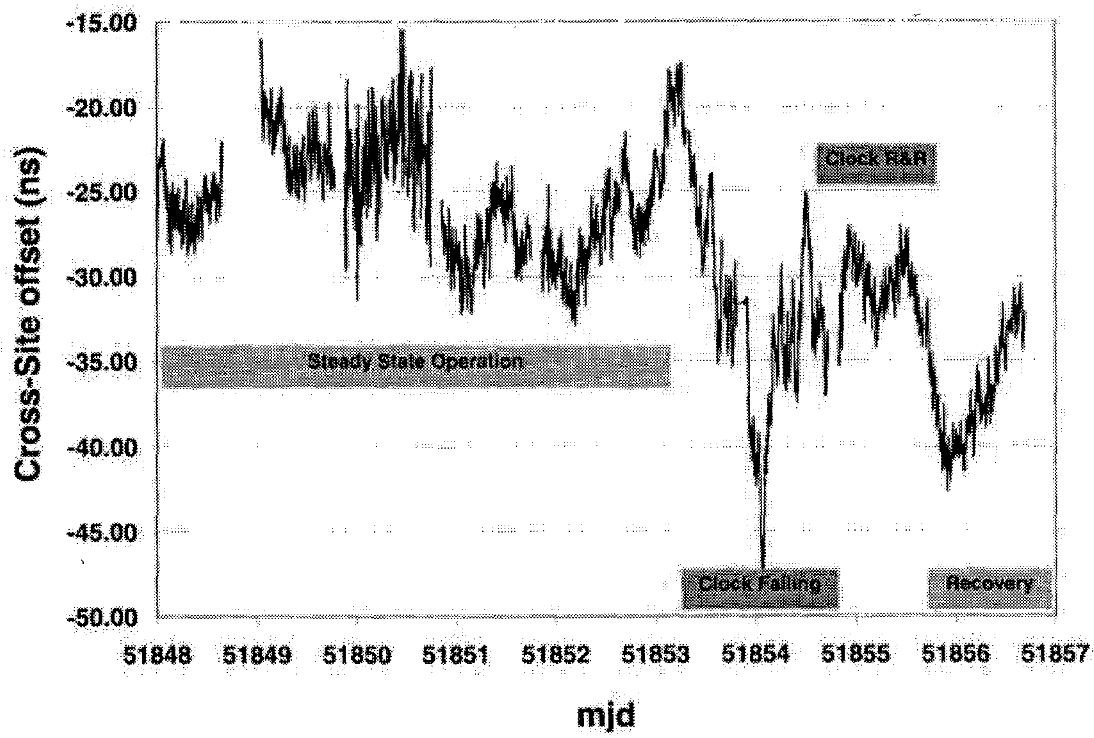

Figure 4: OTA Data

4.0 DATA CORRECTIONS

The use of commercial modems for timing becomes challenging as the precision level required gets better. Commercial satellite modems are not designed or manufactured with time-transfer requirements in mind. Although bit synchronization at higher bit rates requires better clock recovery, the absolute delay stability is not an issue. There are two primary effects that have been observed while using commercial satellite modems for time transfer. The first effect is a direct correlation between bit rate and timing stability. The second effect is the dependence of modem propagation delay on temperature. These two effects are discussed in detail below.

4.1 Bit Rate

Commercial satellite modems are typically manufactured to operate over a large range of data rates. The Radyne/Comstream modem used for the transatlantic demo has been tested at rates ranging from 128 kbps to 1.544 Mbps. The jitter on the received signal is directly relatable to the bit rate. Figure 5 shows the dependence of the two-way RMS on the achieved bit rate and how it relates to averaging time. The RMS stability of the raw data is seen in the blue curve. The raw data stability ranges from 5ns at 1.536 Mbps to 50 ns at 128 kbps. The goal of this measurement is 1-ns RMS and averaging times are chosen accordingly. Figure 5 shows that 100-second averages are sufficient to achieve sub-nanosecond performance at bit rates over 512 kbps and below 512 kbps it is necessary to use a longer average.

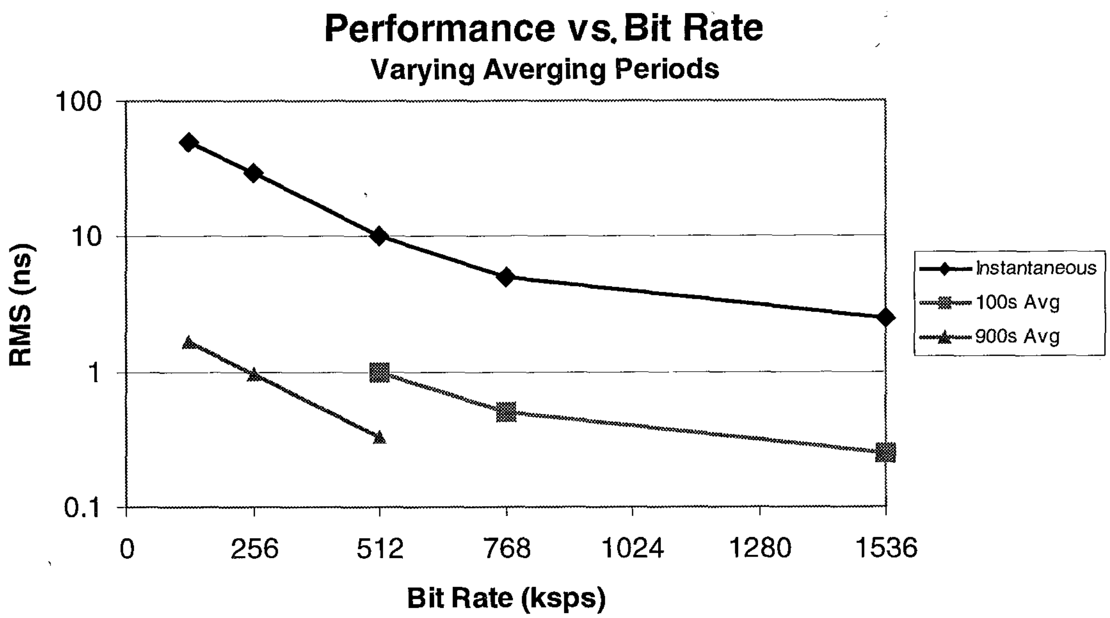

Figure 5: Performance vs. Bit Rate

For the transatlantic demonstration, a data rate of 256 kbps (before coding) was used. Although a higher rate would have allowed shorter averaging times, the link rate choice was driven by the power limitations of the DSCS satellite. The actual channel bit rate was higher than 256 kbps due to the use of Viterbi 7/8 and Reed Solomon coding. The data rate was changed to 128 kbps for a day to show the higher noise level. This is highlighted in Figure 6.

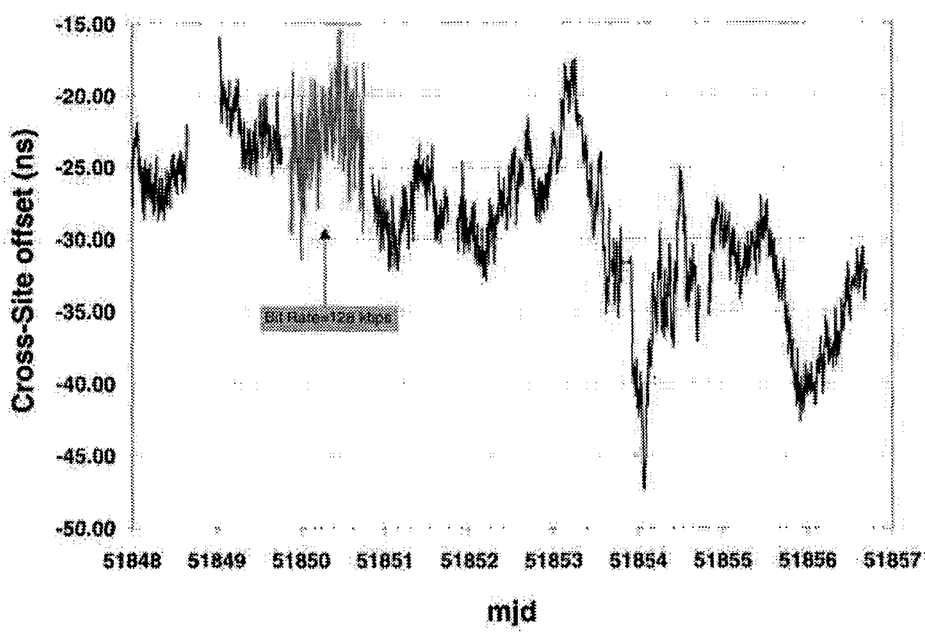

Figure 6: Elevated Noise due to Lower Bandwidth

4.2 Temperature

Commercial modems have temperature dependencies that must be measured and removed. Due to the requirement to support a wide range of bit rates, the modem design includes a bank of filters between switches where the filter choice is driven by the selected bit rate. These filters have group delay characteristics that vary with temperature. The modems were calibrated in dual temperature chambers prior to the experiment. Temperature coefficients of 1.5 ns/deg F were determined. Temperature sensors were added to the modems to log data during the test. The data were corrected using the temperature information to remove the effect. In order to verify that the correction was being done properly, the temperature was raised in one modem for a 2-day period during the test. Figure 7 shows the temperature record for each side of the link and highlights the two-way data during the period where the temperature was raised at one side. The data do not show any bias due to the change in temperature. This provides confidence that the effects of varying temperature were properly removed.

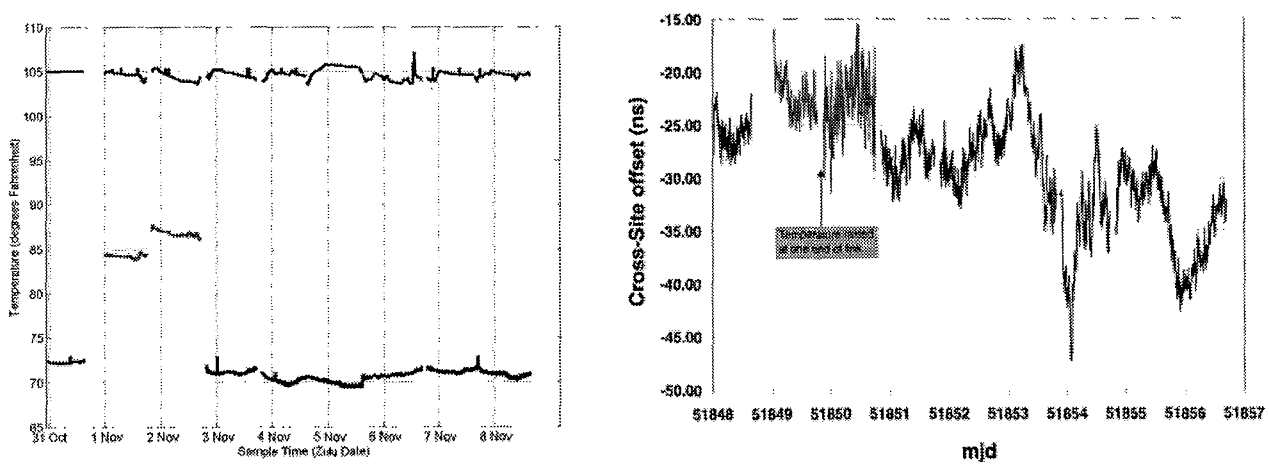

Figure 7: Performance vs. Temperature

5.0 CONCLUSIONS

This paper provides final proof-of-concept for conducting time-based communications over satellite links. The concepts of time-based communications were implemented using a commercial satellite modem. Timing was performed in the background of an active data channel. Data were processed to provide a sub-nanosecond (RMS) continuous estimate of the relative performance of two GPS timing systems. The performance of the system was sufficient to see the steering of the clocks and to detect the failure of a cesium clock in the system. The prototype hardware used for this demonstration had bit-rate and temperature-related performance dependencies that were accommodated and documented during the test.

Time-based communication is a viable option for users who require precision time synchrony and have a communications infrastructure. Timing can be performed in the background with no impact to data users (negligible bandwidth is used). The concepts of time-based communications extend to any two-way communications channel and have been demonstrated at the 20 picosecond level over fiber.

6.0 REFERENCES

[1] T. P. Celano, S. P. Francis, and G. A. Gifford 2000, *"Continuous two-way time transfer using commercial modems,"* Proceedings of the 2000 IEEE/EIA International Frequency Control Symposium and Exhibition, 7-9 June 2000, Kansas City, Missouri, USA, pp. 607-611.

[2] M. Calhoun, P. Kuhnle, R. Sydnor, S. Stein, and G. A. Gifford 1997, *"Precision time and frequency transfer utilizing SONET OC-3,"* Proceedings of the 28th Annual Precise Time and Time Interval (PTTI) Applications and Planning Meeting, 3-5 December 1996, Reston, Virginia, USA, pp. 339-348.

Questions and Answers

HUGO FRUEHAUF (Zyfer, Inc.): Can you do this during normal communications? And, how much overhead would you require to practically make this happen?

THOMAS CELANO: In the case that I just showed you, we were doing normal communications throughout. In order to show that we were not affecting the bit error rate of the link, we were conducting normal communications. And yes, this is intended to be conducted in the background. In this particular case, on a 256 kilobit per second channel, we were taking 9600 bits per second. We were taking an engineering service channel, so it's really minimal to what they were doing. They didn't notice we were doing it.